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Envelopes for Robotic Balloon Vehicles

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Abstract 233 words

Use of robotic balloons, or aerobots, is king planned for mobile exploration of planets. In this paper we focus on the development of balloon envelopes for the. three classes of balloons which are being considered. The type of balloon depends on the planetary environment in which the. aerobot has to operate and on mission requirements.

Venus aerobots will use the hot Venus surface to evaporate balloon fluids to provide. buoyancy; in the upper cooler atmosphere the fluid condenses, allowing the Ic-descent of the aerobot. Structural design and material systems capable of surviving the hot, corrosive environment have been identified and tested. Envelope configuration, and fabrication and assembly techniques arc yet to be demonstrated. Titan aerobots will use the same approach, but the mission environment requires operation at cryogenic temperatures.

For planning a Mars 2001 mission, results of the earlier French/Russian studies, as well as the US terrestrial high altitudes balloons experience are being used. Mars aerobots will use overpressure balloons without landing capability. Required additional studies on design anti materials have been identified.

Recent JPL studies have shown that for outer gas planets (Jupiter, Saturn, Uranus and Neptune), the use of Infrared Montgolfiere (IRM) appears promising. IRM balloons have been demonstrated in terrestrial flights; they are hot gas balloons that capture infrared radiation from the planet, The balloon envelope development challenges include thermal design along with the identification of materials with appropriate physical, and thermal anti optical properties.

Introduction

Use of robotic balloons, or aerobots, is being planned for mobile exploration of planets[1]. In this paper we focus on the development of balloon envelopes for the three classes of balloons which arc being considered. The type of balloon depends on the planetary environment in which the aerobot has to operate. and on mission requirements, Mission scenarios arc detailed elsewhere.

For Venus and Titan, aerobots will use a balloon altitude control concept[2,3,4] whereby a fluid is evaporated in the lower, warmer atmosphere, thus filling a balloon and generating buoyancy for ascent. The fluid condenses in the. upper, cooler atmosphere, thus decreasing buoyancy and allowing re-descent. The feasibility of altitude control was demonstrated in terrestrial flight experiments[5].

For a Mars 2001 mission, the aerobot will have a "constant" density altitude superpressure balloon capable of carrying a 10 kg payload, and no landing capability'. The development program leverages the earlier French/Russian studies for a now defunct Mars 98 balloon mission, and the NASA experience in terrestrial high altitude balloon technology.

Recent JP1. studies have shown that for the outer planets (Jupiter, Saturn, Uranus, and Neptune,) the use of Infrared Mongolfiere (IRM) balloons appears promising[7]. IRM balloons have been demonstrated by CNES in 30 successful terrestrial flights[8]. For Jupiter, JPL thermal models predict the feasibility of achieving a gross buoyancy of 30 kg, with a payload of 10 kg or more, depending on the weight of the balloon.

Venus

The high surface temperature (740 K), pressure **(95** bars) and corrosive sulfuric acid cloud droplets (Fig. 1) arc a challenge to space systems ant] science instruments. Venus aerobots will use the Venus surface beat to evaporate fluids to fill a balloon on the surface , thus assisting ascent to the cool upper atmosphere. The aerobot will then be cooled and the balloon fluid will condense, allowing re-descent of the aerobot.

(fig. 1: Venus Envirionment)

Mission architectures under study consider aerobots that remain at fixed altitudes, or undergo cyclic operations from high altitude (50 to 60 km) to low altitudes for surface imaging, as well as near surface reconnaissance and periodic in situ surface, measurements. Although each mission architecture will have somewhat different requirements, the general issues pertaining to the environment will be similar.' In all cases materials systems selected for the balloon envelope need to meet the following preliminary functional requirements:

- storage. in a tight package
- survival of balloon deployment
- resistance to the environment (temperature, UV, acid clouds, pressure)
- low absorptivity/emissivity ratio
- compatibility and 10 w permeabi lit y to altitude control fluids, e.g., methylene chloride, ammonia, water, h ydrazine and others
- maintaining structural integrity (temperature excursions between 270 and 740 K)
- available ant] affordable

'1'0 date, aerobot conceptual designs were developed, e.g., scc [9], and' film and fiber materials that meet requirements have been identified and tested[10].

After evaluating several materials on the market, polybenzoxazole (PBO) was selected as the leading candidate that could meet requirements. Dow Chemical Corp. t ransferred its production capability to Toyobo Co., Ltd., and will concentrate on fiber manufacturing technology. Foster-Miller Corp. is developing technology for the production of biaxially oriented PBO films. A summary of PBO properties is given in Fig. 1.

(**fig** 2)

The fabrication of the balloon envelope composite fabric will require a high temperature coating/sealant and a high temperature adhesive scaler for laminating a PBO film onto a PBO fabric. This composite envelope configuration will satisfy structural and permeability requirements. It will require, however, an additional outer coating for protection from acid clouds; a gold coating is the likely candidate.

The fabrication technology remains to be developed. Fabrication details will depend on optimisation balloon design studies. These will consider variations in material properties that can be , determine during fabrication, e.g., film biaxiallity. Studies that need to be performed will include parametric radiative analyses, parametric thermal performance anal yses, balloon mass/volume requirements for desired payloads and material testing in support of above analyses.

Titan

For a Titan aerobot mission[4] a fluid phase, change balloon is being considered. A mode.1 of Titan's atmosphere[4] (Fig. 3) suggests argon (or a mixture with argon) as the reversible balloon fluid. Clearly, the environmental conditions are the coposite extreme of those for Venus. The materials for the balloon envelope will have to function at cryogenic temperatures and no talloow losses of argon a highly permeable gas.

(fig 3 Titan atmosphere)

Mars

For a Mars mission the fluid phase change balloon concept is impractical because of the extremely rarified atmosphere; no useful payload could be flown. Instead, a constant densit y altitude superpessure balloon system without landing capability is being considered. A cylindrical balloon with a diameter of 18 m having a volume of about 2,400 m^3 would be capable of carrying a 10 kg gondola with a 3-4 kg science. payload[6]. Mylar is the base-line material of construction The development of this aerobot will rely on the experience gained during studies for the now defunct French-Russi an Mars 1996 balloon mission'[1]; these studies included terrestrial demonstration flights. Nevertheless, a number of structural and material issues rennin to be resolved.

Design issues include envelope robustness in order to survive temperature. excursions (down to 160 K), the.rma] performance and ability to withstand deployment ancl inflation stresses. Other environmental factors are: possible high surface winds, increases in overpressure clue to insulation.

A major technological challenge is overcoming the effects of fluctuations in thermal/radiative characteristics that influence the performance of the ball oon. The impact of the radiative properties of various coatings on balloon temperature and differential pressures for the given radiative and atmospheric condit ions wi ll be estimated by means of parametric st udies. Further, parametric analyses will be performed on effects of the environment on balloon temperat ure, differential pressure, and altitude excursions; assess requiremetns to necesary to prevent the a aerobot from impacting the surface.

Outer Planets

A phase-change fluid is not practical for~.outer gas planets because they are at least 80% hydrogen, with the remaining atmosphere being primarily helium. Thus in order to float a 10 kg payload in the Jovian at mosphere approxi matel y 1000 kg would be needed for the h ydrogen, balloons, t ankage, phase-change fluids., and entry-vehicle[7].

JPL . studies showed , however, that light weight controllable balloon systems using lower planetary radiation heating appear feasible for the outer planets[7]. The feasibity of flying Infrared Mongolfiere (IRM) balloons was demonstrated by a series of flights by the French[8].

Recent analyses at JPL show that IRM tecnology appears very relevant for missions to the giant gas planets. The increased convective hydrogen cooling of the outer gas planet balloons appear to be more than compensated by, by the radiative T^4 heatingat planet's lower altitudes, thus allowing operation at altitudes corresponding to 0.3 bar or lower[7]. A sketch of the French IRM balloon is shown in Figure **4,** and typical altitudes attained are shown in Figure S.

Fig 4

Fig 5

A Jupiter IRM would rely on the internal radiated Jupiter IR lux to heat ambient balloon atmosphere. The density of the Jupiter's atmosphere at about 5 bar level (27 1 K) is about equal to Earht's atmosphere at 0.35 bar, or the range where the French balloons floated. JPL themal models predict for a balloon 15 m in diameter and weighing about 20 kg the feasibility of a gross buoyancy of about 30 kg or payload of 10 kg.

in the near future thermal modelinstudie swill be performed to predict performance in the Jovian atmosphere. Atmospheric models will be updated with the data from the Galileo probe .

The reaults from the thermal modeling studies will guide the design of the balloon and the selecrion of materials of construction (envelope materials, infrared absorber coatings, and reflector coatings.)

These studies will be followed by similar studies for other gas planets (Saturn, Uranus and Neptune.)

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Acknowledgments

The research described in this publicaiton was carried out by the Jet Propulsion laboratory, California Institute of Technology, under contract withth eNational Aeronaut ics and Space. Administrate ion,

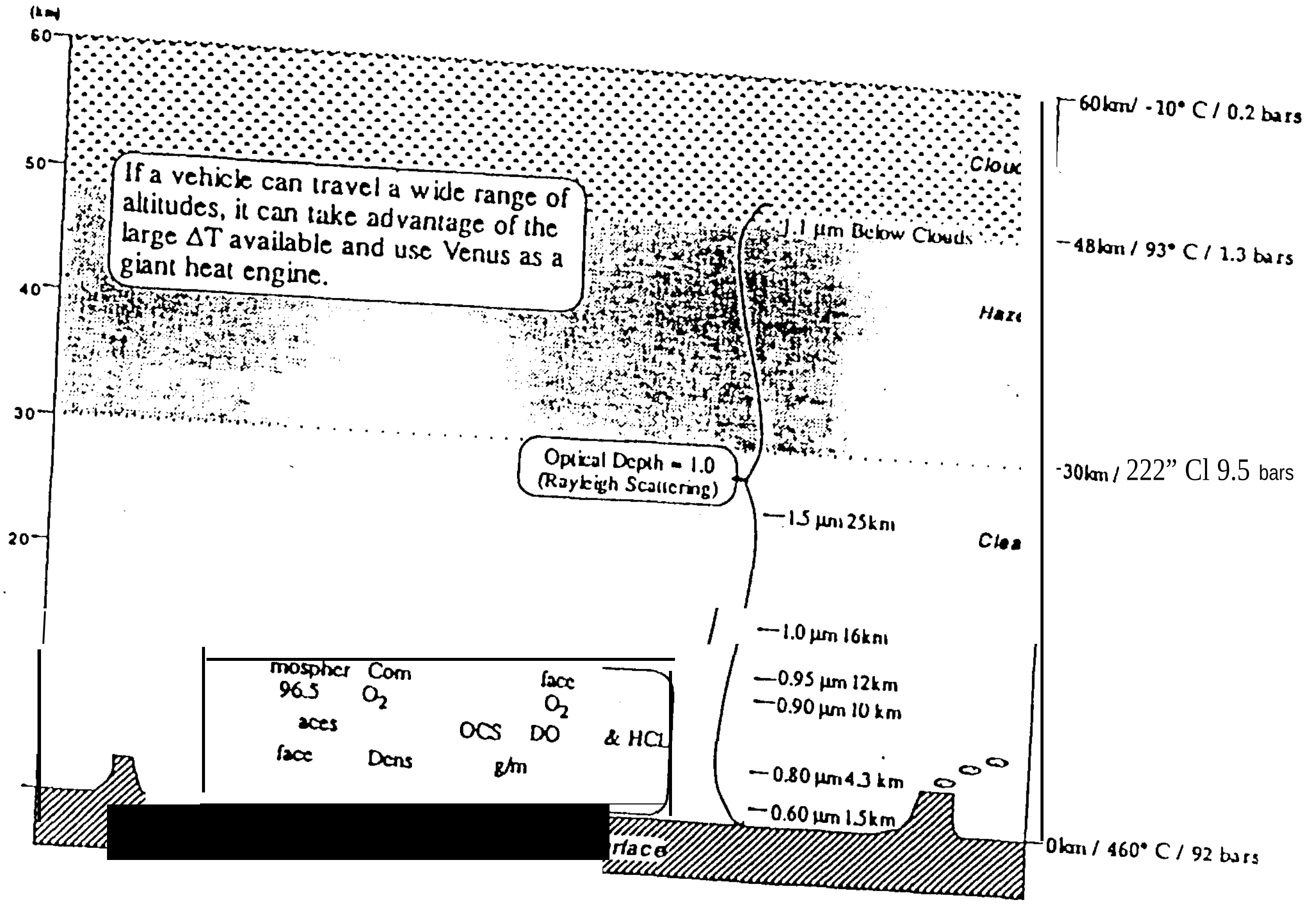


Fig. 1. Venus Environment.

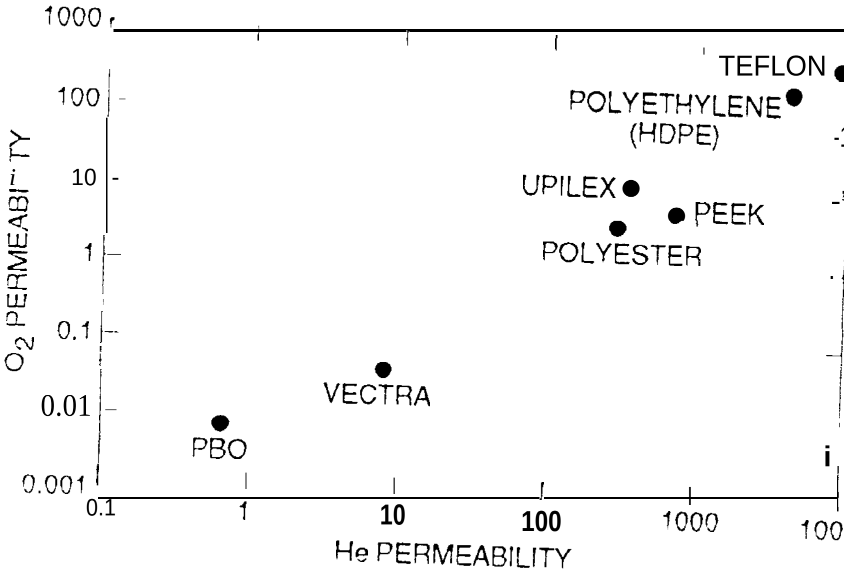
Fig 2:

JPL

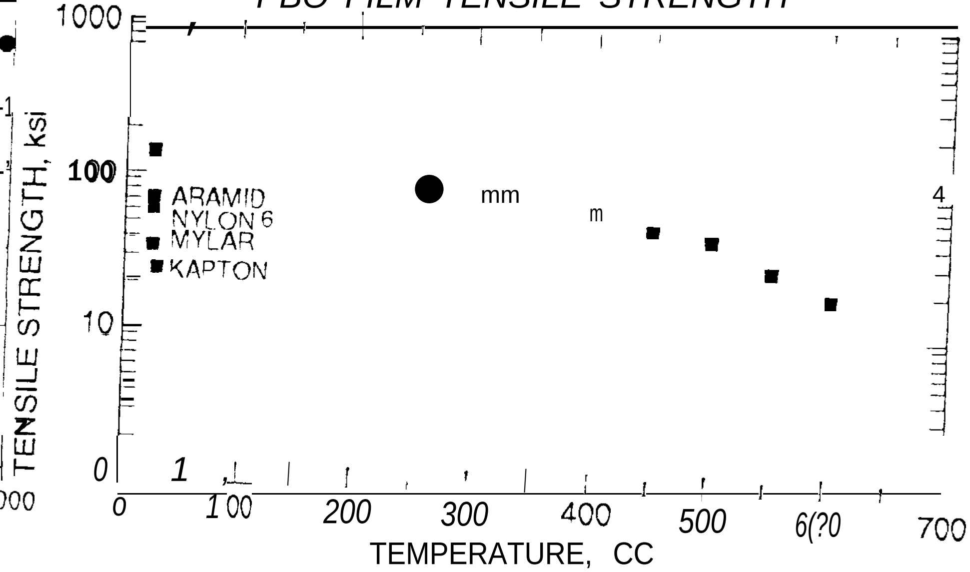
PLANETARY AEROBOTS

PBO PHYSICAL PROPERTIES

PERMEABILITY COMPARISON DATA



TEMPERATURE DEPENDENCE OF PBO FILM TENSILE STRENGTH



SPECIFIC TENSILE STRENGTH PBO FIBERS (DOW DATA), ksi

ARAMID	**280-350**
STEEL	**32**
SPECTRA® (HDPE)	**450**
CARBON	**270-380**
GLASS	**280**
PBO	**510- 525** **(16-TIMES STEEL)**

EFFECT OF THERMAL CYCLING ON TENSILE STRENGTH OF PBO FILM

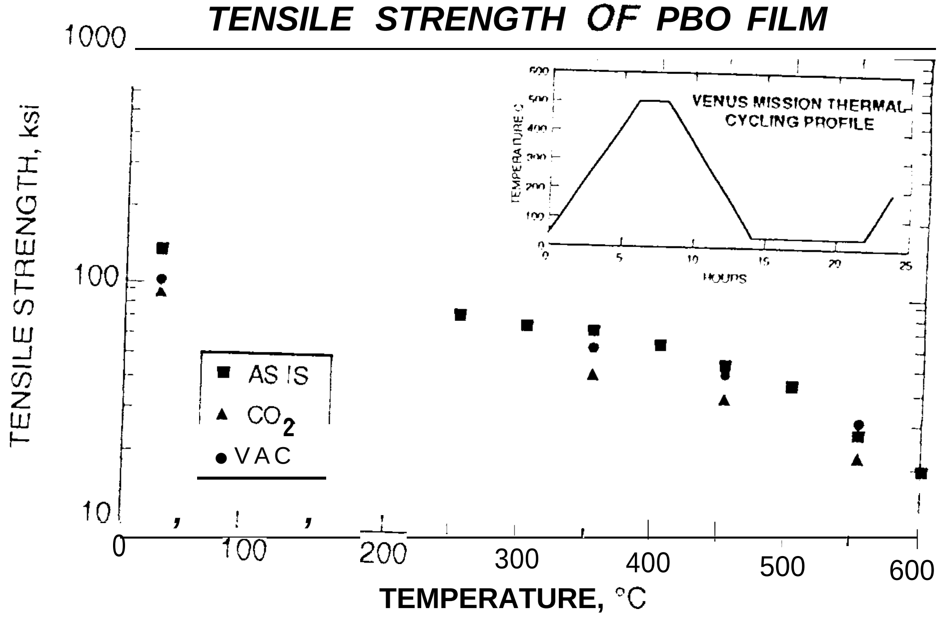
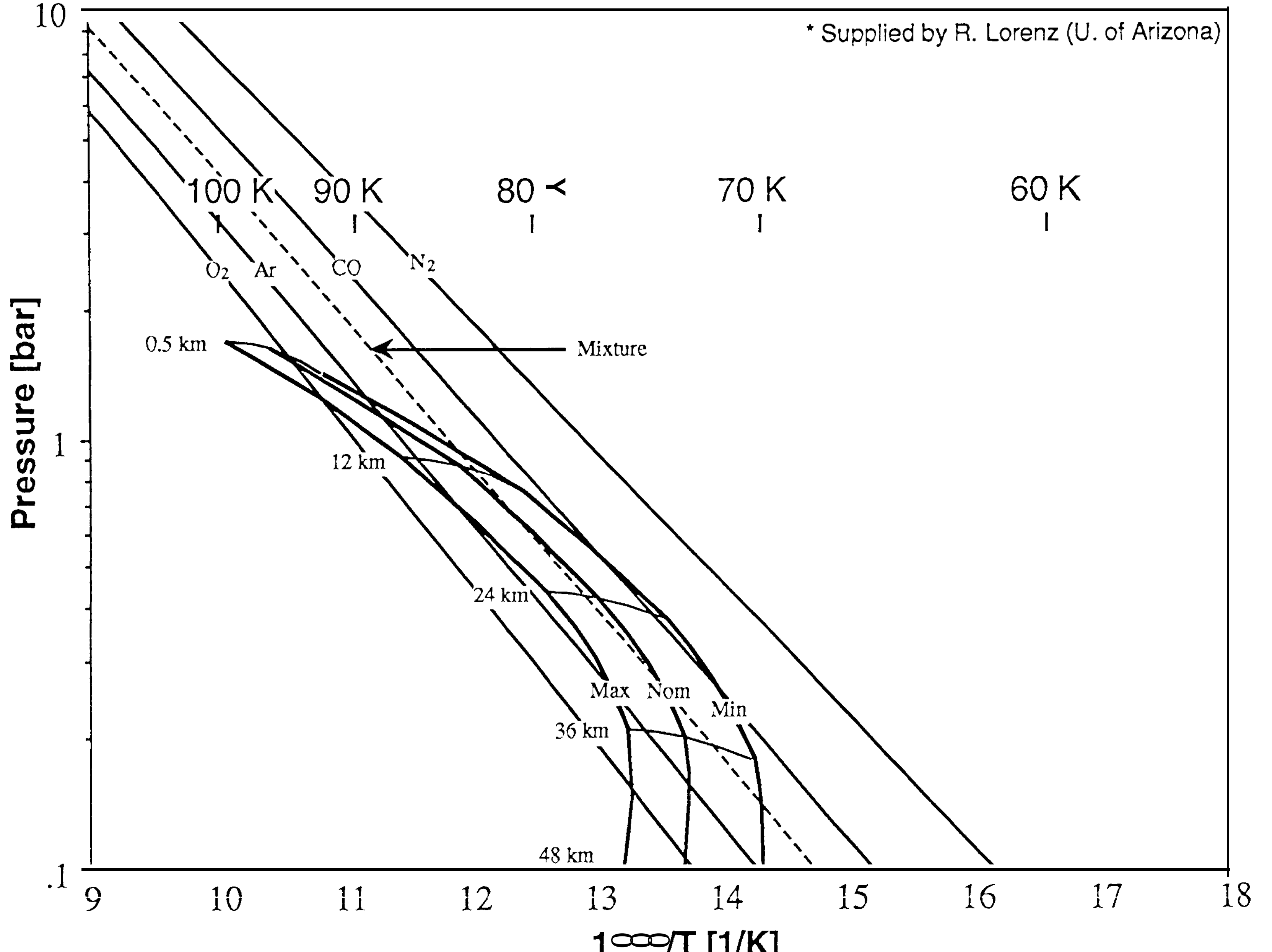


Fig 3

A Model of Titan's Atmosphere* and Possible Reversible Fluids for Aerobots



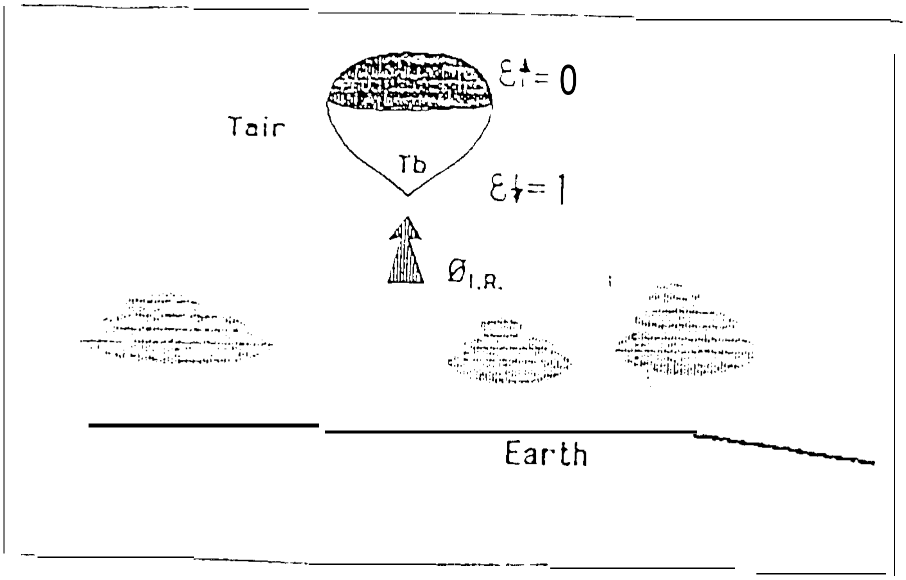


FIGURE 4. PRINCIPLE OF INFRARED MONTGOLFIERE BALLOON

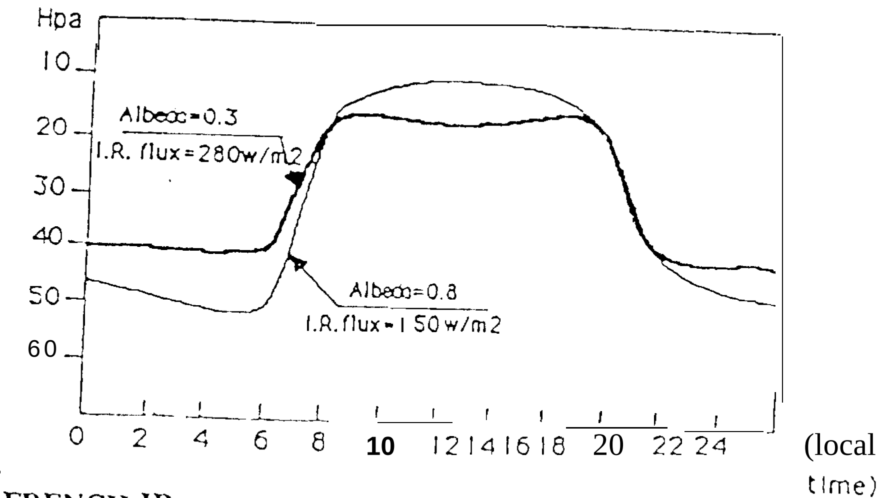


FIGURE 5. FRENCH IR BALLOON DATA FOR PRESSURE (ALTITUDE) vs. LOCAL TIME